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# Optimal loading for force production in the straight bar deadlift: Force-time characteristics in strength trained adults

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**Abstract**

This study sought to identify whether there is an optimum load in relation to peak force development and rate of force development (RFD) in the straight bar deadlift and to examine whether baseline strength levels influence this optimum load. 12 strength trained males (mean age ± SD = 25.1 ± 5.4 years) performed 3 deadlift repetitions at loads at 10% intervals of 20-90% of their predetermined individual 1RM. Peak vertical force (PFz) and RFD was determined from each repetition. The repetition at each percentage of 1RM that produced the greatest PFz was used for analysis. All data were collected on an AMTI force platform. Repeated measures ANOVA indicated significant differences in PFz across loads of 20-90% 1RM (P = .001) with a linear increase in PFz with increasing % of 1RM. The highest PFz occurred at 90% of 1RM. For RFD there was a significant main effect for load (p = 0.018) where instantaneous RFD was significantly higher at 80 and 90% 1RM compared to 20% 1RM. When analyses were rerun using baseline strength as a covariate, the results did not change, indicating that baseline strength did not influence the PFz or RFD output. These results suggest that there is no significant difference in RFD between adjacent loads but that peak force production was greatest at 90% 1RM in the straight bar deadlift.

**Keywords:** Resistance training, Strength, Rate of Force Development; Peak Force

**Introduction**

Performance within many sports is fast paced and complex, often requiring the ability to generate high amounts of maximal force in the shortest time possible (5,20, 24,27,31). This is often associated with an athlete's overall strength levels and ability to express high power outputs (15,17), with a clear relationship between the ability to produce high power outputs and sports-specific movements (4,28). Consequently, there has been considerable interest in the effectiveness of different training methods to enhance peak power output, with optimal loading being considered of importance (30). Many studies to date have focused specifically on determining the load that achieves the greatest peak power output across various exercises (6,7,11,36,39).

Although authors have examined this concept, results from the literature are equivocal and the spectrum of 'optimal loads' varies from 0-80% of 1RM (7,11,32,38,39). Some researchers suggest (23,26) that light-load training strategies (<30% 1RM) have greater effects on power development than heavy-load training (>80% 1RM), whilst others suggest the opposite (22,35). However, despite this concept, to be able to apply these high peak power outputs requires the capability to contract high levels of force rapidly (20), as acceleration during a movement causes the time frame for force application to be short (27). The ability to produce rapid and high levels of force in short time intervals is also integral for athletic performance (14). This is replicated by the rate of force development (RFD), which is of significant functional importance (1), and is vital in the expression of power (16,27). Peak force and RFD are significant variables that contribute to power development (14) which is an important attribute that needs to be developed and implemented within a training programs (16).

Effective training methods to produce a high RFD is desirable, as establishing whether there is an optimal load that results in the most favourable adaptations in muscular power is important. This could lead to the possibility offering the possibility more refined training practices and enhanced adaptation for power output development. Authors have recommended the use pf light loads for optimization of RFD (13,27); however little evidence for this concept exists and the optimal load for producing the greatest increase in RFD remains unknown.

The deadlift is an exercise performed in a variety of training settings and is a popular resistance training exercise in both athletic and recreationally trained individuals. The deadlift has traditionally been used to develop maximal strength (31,33) and maximal power (34), although research has tended to examine mechanical variables during maximal deadlifts only (33). Swinton et al. (35) compared kinetic and kinematic variables between the straight bar and hex bar deadlifts, reporting that irrespective of bar, peak force increased significantly across loads from 10 to 80% 1RM with a subsequent reduction in peak velocity as load increased. No study has examined whether there is a load that optimizes the RFD. Other studies, however have identified an optimum RFD and peak force with respect to Olympic lifts, such as the power clean (9,10).

The current study sought, firstly, to identify whether there is an optimum load in relation to peak force development and RFD in the straight bar deadlift, and secondly, to examine whether baseline strength levels influence this optimum load.

## Methods

### Experimental Approach to the Problem

A cross-sectional, repeated measures design was used where data collection took place across two testing sessions separated by at least 72 hours. In the first testing session, participants attended the human performance laboratory and were familiarized with the equipment, exercise execution, testing procedures, and underwent one repetition maximum testing (1RM) on the straight leg deadlift. The second testing session comprised performing the straight leg deadlift at loads ranging from 20-90% 1RM (10% increments) with loads executed in a randomized order. Force-time characteristics (peak force and RFD) were subsequently calculated across each of the 10% load increments.

**Participants**

Following institutional ethics committee approval and signed written informed consent, 12 male participants aged 19-36 years volunteered to take part in the study. The participants were all regular exercisers with a training age of at least 2 years (mean training age = 6.5 ± 5.4 years). Participants were actively engaged in approximately 12 hours per week of structured exercise including resistance exercise training. Participants were from a variety of team sports (e.g. basketball, soccer, and rugby union) and all experimental testing took place within the pre-season preparatory period of their respective sports. A priori power analysis, based on differences observed in our laboratory for peak force in the deadlift at intensities of 60-70% 1RM, indicated that a sample size of 12 participants was needed to detect a small effect size of .25 at 80% power with a p of 0.05. This effect size and power estimate were selected based on the aforementioned pilot data collected in our laboratory and observed values for power in the deadlift reported in prior studies (33). The participants were instructed not to consume alcohol or caffeine from 6.00 pm the night before the testing sessions. Participants were also instructed to avoid participation in any structured exercise training in the 24 hours prior to each experimental condition and to maintain the same dietary patterns during this period. Participants were further instructed to report to the laboratory well hydrated. Pre-test conditions were verbally queried and confirmed by participants on each testing occasion upon arrival at the laboratory. Participants were excluded if they had (1) muscle, bone, or joint impairment/injury that could impede their performance of the exercise (2) a training age of less than two years or (3) no previous experience performing the straight bar deadlift. Baseline participant characteristics are presented in Table 1.

***Table 1 here***

## Experimental Protocol

Each participant attended the human performance laboratory on two occasions. The first session to the laboratory involved a full briefing about the study and determination of participant's 1RM on the deadlift. All participants had experience performing this exercise in particular. However, prior to commencing the 1RM testing, each exercise with correct lifting technique was demonstrated to the participant. The 1RM was determined according to methods advocated by Kraemer et al. (21). Firstly, the participant performed a specific warm-up, of five-ten repetitions at light-moderate load and rested for one minute before the 1RM protocol begun. An estimated warm up load was added (10-20%) that allowed the participant to complete three-five repetitions, then followed by two minute rest period, a further 10-20% was additionally added for an estimated near-maximal load allowed for the participant to complete two-three repetitions this time followed by a two-four minute rest period. Once completed a further 10-20% increase was added and the participant was instructed to attempt 1RM. If successful, 10-20% increased to load, if failed a 5-10% subtraction of load was applied and 1RM was attempted again. The continuation of either an increase or decrease of load was applied with a two-four minutes rest, until participant completed 1RM with proper exercise technique (21). The 1RM gained was used to set the 20% - 90% 1RM intensities undertaken during the proceeding experimental trial.

In the subsequent session, one week post 1RM testing participants performed three repetitions of the deadlift at each load from 20% - 90% of 1RM, in a randomized order. Rest periods between 3-5 minutes were given between each repetition and load respectively to decrease the effects of cumulative fatigue. All participants were instructed to perform the deadlift as quick as possible after command of '1,2,3, Go'. All deadlifts were performed with participants standing on an AMTI force platform (*BP600900, AMTI, Watertown, MA, USA*), sampling at 1,000 Hz, interfaced with a PC. Initiation of movement was identified as the point at which vertical ground reaction force was greater than 5SD of the quite standing period. Data (unfiltered) were later analyzed using Microsoft Excel, to determine peak force ($PF_z$). Instantaneous RFD was determined by dividing the difference in consecutive vertical force readings by the time interval (0.001 seconds).

**Lifting Procedures**

All exercises were performed using a 20kg Eleiko bar (Eleiko Sport AB, Halmstad, Sweden), and Olympic lifting platform (Pullum Power Sports, Luton, UK). All lifts were completed in accordance with protocols previously described, by Haff and Tripplett (18), for the deadlift (See Figure one). Deadlifts were performed with a conventional shoulder width stance and deemed to be successful if the barbell was not lowered at any point during the ascent and upon completion of the movement the body posture was erect, the knees were straightened and the shoulders retracted. Participants were instructed to keep their elbows straight during the lift and not to jump with the weight. If these requirements were not met, the trial was repeated. A trained researcher/spotter was present during all testing sessions to ensure full range of motion. Any lift that deviated from correct technique was not counted.

***Figure 1 here***

## Submaximal Testing

Before submaximal testing, subjects performed a dynamic warm up consisting of four sets of eight-ten repetitions on the deadlift at a load of 30% 1RM. Such procedures are broadly consistent with those reported previously (9,10,35). Once prepared, participants performed the deadlift trials at loads of 20-90%1RM in a randomized order. Three repetitions were performed at each load and subjects were instructed to perform each repetition with maximal effort attempting to lift the load as fast as possible. A three minute rest period was allocated between trials and a five minute period was allocated between loads. For each load, the trial that produced the greatest peak force was used for further analysis.

## Statistical Analysis

Intraclass correlation coefficients (ICCs) were calculated to assess intra-trial reliability. To examine whether there were any differences in $PF_z$ and RFD, two, repeated measures analysis of variance (ANOVA) were used, where differences in the dependant variables (either $PF_z$ or RFD) were examined across the eight loads (20-90%1RM). In the case of significant main effects, Bonferroni post-hoc multiple comparisons were used to determine where the differences existed. A p value of 0.05 was used to indicate statistical significance. Partial eta squared ($\eta^2_p$) was used as a measure of effect size to determine the magnitude of any differences in $PF_z$ or RFD between loads. $\eta^2_p$ is commonly used in repeated measures designs, providing the ratio of variance associated with an effect, plus that effect and its associated error variance and allows the assessment of how large a difference between two conditions is, rather than simply stating two conditions are different, as is the case with p values alone (29). In order to examine whether baseline strength influenced the results, the analysis was repeated using baseline strength (1RM) as a covariate. All statistical analyses were performed using the Statistical Package for Social Sciences (SPSS, version 20, IBM Corp, Armonk, New York).

## Results

Intra-trial reliability for $PF_z$ and RFD at each load were all high with a trend to higher reliability with increasing load. Intraclass correlation coefficients for $PF_z$ and RFD across loads are presented in Table 2.

***Table 2 here***

Regarding $PF_z$, results from repeated measures ANOVA revealed a significant main effect for load (F7,77 = 32.3, p = 0.001, $\eta^2_p$ = .746). Mean ± SE of $PF_z$ across loads is presented in Figure 2. Bonferroni post hoc pairwise comparisons indicated that $PF_z$ significantly increased as load increased. $PF_z$ at each load was significantly different to each other (all p < 0.01) with the exception of $PF_z$ between 30 and 40%1RM (p = 0.465) and $PF_z$ between 50 and 60% 1RM (p = 0.087). Percentage difference were 12% between 20-30% 1RM, 8% between 40-50% 1RM, 6% between 60-70% 1RM, 4% between 70-80% 1RM and 5% for 80-90% 1RM. When analysis was re run using 1RM as a covariate the results of the analysis remained the same and 1RM value was not significant as a covariate (p > 0.05).

***Figure 2 here***

For RFD, results from repeated measures ANOVA revealed a significant main effect for load (F7,77 = 2.610, P = .018, $\eta^2_p$ = .192). Mean ± SE of RFD across loads is presented in Figure 3. Bonferroni post-hoc pairwise comparisons indicated that instantaneous RFD was significantly higher at 80% 1RM (p = 0.05, 52%) and 90% 1RM (p = 0.04, 51%) compared to

20%1RM. RFD was not significant between any other loads. Similar to $PF_z$, when the analysis was repeated using 1RM as a covariate, the results were the same in that 1RM value was not a significant covariate ($p > 0.05$).

***Figure 3 here***

## Discussion

This study examined whether there is an optimum load to improve force production, with respect to peak force development and instantaneous RFD, in the straight bar deadlift. The study also sought to examine the influence, if any that baseline strength has on optimum peak force or RFD. For both $PF_z$ and RFD, the results of the present study show no one optimum load where $PF_z$ and RFD are maximized. There was an almost linear increase in $PF_z$ as load increased and RFD was not significantly different across 30-90% 1RM. There was also considerable variation in the RFD values as demonstrated by relatively high SE values across loads. It can be assumed however, that a combination of greater $PF_z$ and higher instantaneous RFD relates to greater peak power output. Such a suggestion has been made previously (9). In the present study as PFz was highest at 90% 1RM, this intensity should be considered the one where peak force is maximized during the deadlift.

In the current study there was no peak in RFD. This is in agreement to previous findings by Kilduff et al. (22) who reported relative load had no effect on peak RFD during a hang clean exercise with professional rugby players. Evidence has suggested that, regardless of training load, the most efficient training modalities are ones where muscle actions performed with maximal intentional RFD (37). This suggestion aligns with the findings of the current study, however although the deadlift has been used by athletes to enhance power (33), the deadlift is not widely regarded as an explosive-type exercise.

In the current study, $PF_z$ increased as a function of load, demonstrating a linear increase. This finding agrees with previous studies (7,19,11,22). The highest $PF_z$ within this study was identified at 90% 1RM. Likewise, the results of the current study are comparable to research by Comfort et al. (9) who reported that force production during power clean was linear in nature. A further study (11), examining $PF_z$ during the power clean, back squat and jump squat increased linearly from 0-85% 1RM within all three exercises. In the current study, analysis also considered baseline strength as a covariate as suggested by prior authors (25) as baseline strength may be important. In the present study, 1RM values did not appear to influence the results of the statistical analysis. This may be due to the participant group. All individuals who undertook the study had at least two years resistance training experience, including experience with Olympic lifts. This may have resulted in a more homogenous sample than the study by Lyons et al. (25) who used team sports players.

The current study is not without limitations. A minimum training age of two years was employed as an inclusion criterion in the present study. This was used to ensure participants were technically proficient in the deadlift and the results obtained were representative of resistance trained individuals. However, whether an optimum load is evident in novice lifters has yet to be established. Likewise, the participants in the current study, although engaging in regular strength training were not specialist strength athletes (e.g., weightlifters, powerlifters). Therefore, the results presented here may not be translatable to athletic groups where weightlifting is the sole outcome of performance. Additionally, future research is needed that establishes whether there is an optimum load and then compares these optimum loads across multiple different lifts; e.g., deadlift, back squat, power clean, mid-thigh pull. This type of work would be useful in establishing an optimum loading profile for a range of commonly used resistance exercises.

**Practical applications**

From the results of the present study, suggest that no single optimum load to maximise $PF_z$ and RFD in the straight bar deadlift was evident. In the case of $PF_z$ greater values were evident at higher loads (90%1RM) with an almost linear relationship between $PF_z$ and load being evident. For instantaneous RFD there was little significant difference in RFD across trials with only values at 20% 1RM being significantly lower than other loads.

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**Figure Legends**

Figure 1. Example Force Plate data collection during the straight bar deadlift.

Figure 2. Mean ± SE of Peak Force ($PF_z$, N) during straight bar deadlift across loads (%1RM) (P values shown for adjacent loads)

Figure 3. Mean ± SE of instantaneous RFD (N/s) during straight bar deadlift across loads (%1RM)


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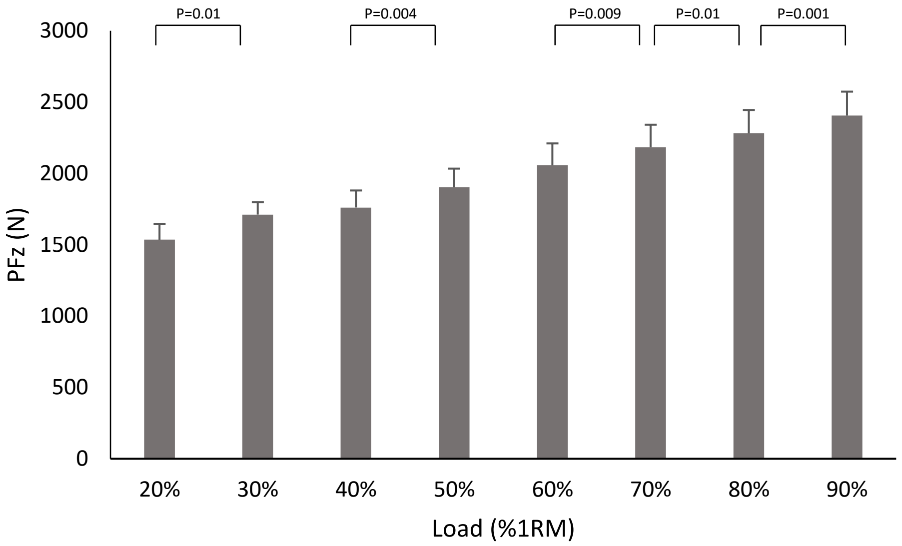
Figure 1.



P=0.01
P=0.004
P=0.009
P=0.01
P=0.001
3000
2500
2000
1500
1000
500
0
PFz (N)
20%
30%
40%
50%
60%
70%
80%
90%
Load (%1RM)


Figure 2.

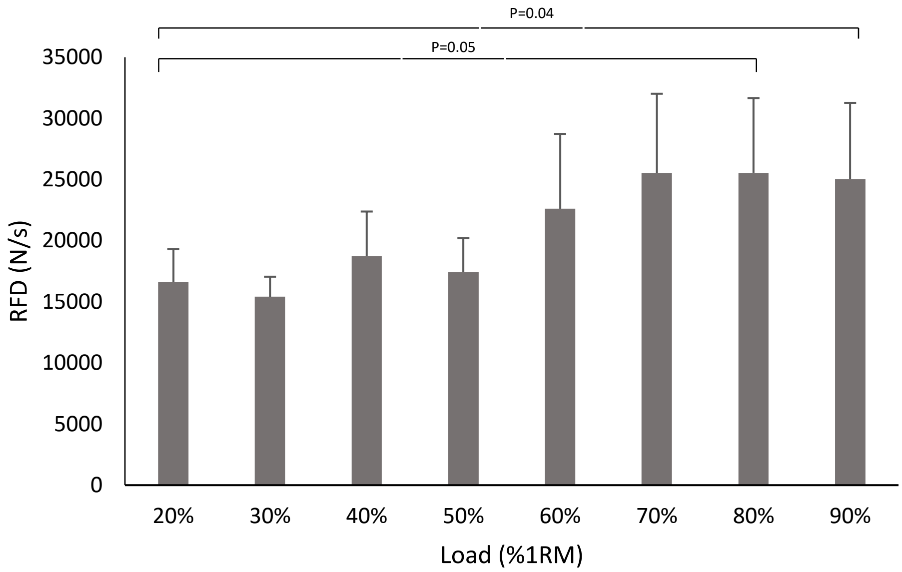

P=0.04
P=0.05
35000
30000
25000
20000
15000
10000
5000
0
RFD (N/s)
20%
30%
40%
50%
60%
70%
80%
90%
Load (%1RM)

Figure 3.

Table 1. Participant characteristics (Mean ± SD)

| | Mean | SD |
|---|---|---|
| Age (years) | 25.1 | 5.4 |
| Height (m) | 1.77 | .11 |
| Body Mass (kg) | 81.5 | 12.5 |
| 1RM (kg) | 165.2 | 36.1 |

Table 2. Intraclass correlation coefficients for $PF_z$ and RFD across loads

| | Load (%1RM) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 20% | 30% | 40% | 50% | 60% | 70% | 80% | 90% |
| $PF_z$ | .923 | .880 | .923 | .969 | .984 | .939 | .966 | .980 |
| RFD | .871 | .798 | .812 | .820 | .909 | .942 | .948 | .953 |